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METHODS OF MEASUREMENT OF PROPERTIES OF ELECTRICAL INSULATING MATERIALS.

By J. H. Dellinger and J. L. Preston.

ABSTRACT.

The Bureau of Standards receives frequent requests for information on the methods which it has found practicable for making measurements of properties of electrical insulating materials. The methods are described in this paper.

In Technologic Paper No. 216, Properties of Electrical Insulating Materials of the Laminated, Phenol-Methylene Type, the authors have indicated the reasons for selecting certain of the physical properties for measurement in a research on electrical insulating materials. The same considerations apply in the measurement of many types of insulating materials besides the laminated phenolic materials. The information obtained by making measurements for a given material on all these properties is quite comprehensive. The properties for which methods of measurement are given are: Phase difference and dielectric constant at radio frequencies, voltage effects at radio frequencies, volume resistivity, surface resistivity, density, moisture absorption, tensile strength, transverse strength, hardness, impact strength, permanent distortion, machining qualities, thermal expansivity, and effects of chemicals.

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I. INTRODUCTION.

In Technologic Paper No. 216, Properties of Electrical Insulating Materials of the Laminated, Phenol-methylene Type, the authors have indicated the reasons for selecting certain of the physical properties for measurement in a research on electrical insulating materials. The same considerations apply in the measurement of many types of insulating materials besides the laminated phenolic materials. The bureau has received frequent requests for information on the methods that have been found practicable in making these various measurements. The methods are described herein. The definitions of the various properties are given in Technologic Paper No. 216.

II. PHASE DIFFERENCE AND DIELECTRIC CONSTANT.

Insulating materials are not perfect in their insulating qualities, and there is a certain amount of power absorbed in them when used in or near a circuit in which alternating current flows. This effect is particularly important when the frequency is high, and it has been shown, in fact, that the power loss is the best single property that gives an indication of the suitability of an insulating material for use in high-frequency (radio) apparatus. The power loss can be expressed by a number of constants—the resistance, phase difference, phase angle, power factor, sharpness of resonance, and decrement. The relations between these are given and discussed in a paper by one of the authors.[1]

The simplest of these expressions for the power loss is the phase difference. It is the complement of the phase angle. When the phase difference is small, which is true for practically all insulating materials that are suitable for use in electrical measuring apparatus, the phase difference (in radians) equals the power factor. Power factor in per cent is 1.75 times the phase difference in degrees. Either of these quantities is obtained by measuring the equivalent resistance and capacity of a condenser made up of the material and the frequency of the alternating current used.

A test specimen for the measurement of phase difference and dielectric constant at radio frequencies consists of a sheet of the insulating material placed between metal plates, the whole constituting an electric condenser. It has been found most convenient and satisfactory to use mercury as the metal for the condenser plates. The sheet of insulating material is floated on

[1] J. H. Dellinger, The Measurement of Radio-frequency Resistance, Phase Difference, and Decrement, Proc. I. R. E., 7, p. 27; 1919.

mercury and a pool of mercury formed on top of the sheet, confined by strips of copper. Tin foil and graphite were also tried as condenser plates, but were found not so satisfactory as mercury.

The phase difference of an electrical insulating material is

$$\psi = 90° - \theta \tag{1}$$

where θ is the phase angle between the current flowing and the voltage across a condenser which has the space between its conducting plates filled with the insulating material. The voltage E (Fig. 1) across the condenser may be considered to be made up of a voltage $\frac{I}{\omega C}$ acting on the capacity and a voltage RI acting on a resistance in series with the capacity. Thus, the condenser is for purposes of measurement considered as equivalent to a

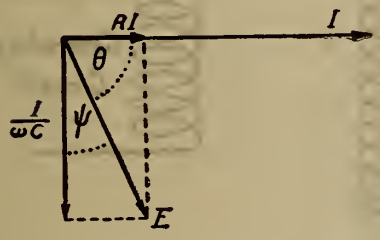

FIG. 1.—*Relations of phase difference, phase angle, current, and voltage.* (The phase difference ψ is magnified.)

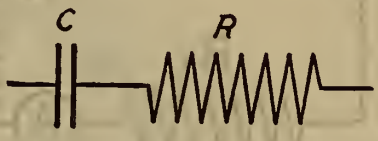

FIG. 2.—*Series capacity and resistance equivalent to actual condenser.*

pure capacity C with a resistance R in series with it (Fig. 2). This resistance is called "effective resistance" or "equivalent resistance" of the condenser, sometimes shortened to simply "resistance." Such a resistance has nothing to do with the direct current or leakage resistance of the condenser.

The phase difference ψ is calculated from the effective resistance and other quantities, as follows: From Figure 1

$$\tan \psi = \frac{RI}{\frac{I}{\omega C}} = R\omega C \tag{2}$$

where $\omega = 2\pi$ times the frequency of the current. Since for small angles, $\tan \psi = \psi$, therefore

$$\psi = R\omega C \tag{3}$$

ψ is known if R, ω, and C are known. A phase difference measurement thus involves a measurement of three separate quantities.

The formula (3) as given is correct for ψ in radians, R in ohms, C in farads. Using wave length in meters (λ_m) in the formula instead of ω, then for ψ in degrees, R in ohms, and C in micro-microfarads,

$$\psi = 0.1079 \frac{RC}{\lambda} \qquad (4)$$

The three quantities involved in the phase difference are measured with radio-frequency currents. Current of radio frequency is caused to flow in a circuit containing the condenser made up from the insulating material which is under test. The frequency or wave length is measured by a wave meter placed near the circuit containing the condenser. (For the principles

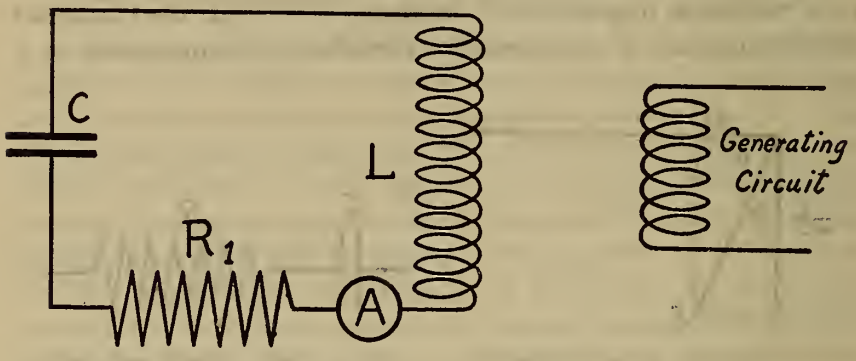

FIG. 3.—*Schematic diagram of apparatus for measuring phase difference.*

of use of a wave meter, see The Principles Underlying Radio Communication, Signal Corps Radio Pamphlet No. 40, secs. 112 and 168; or see Radio Instruments and Measurements, Circular No. 74 of the Bureau of Standards, sec. 28.) The capacity is measured by comparison with a standard variable air condenser (see Circular No. 74, sec. 35) simultaneously with the measurement of resistance. The measurement of resistance is the most important and difficult part of the measurement.

Dielectric constant.—From the measurement of capacity C the value of the dielectric constant of the material is easily obtained. The average thickness T of the dielectric and the surface area S of one of the condenser plates are measured. The dielectric constant is then given by

$$K = 11.3 \frac{CT}{S} \qquad (5)$$

for C in micromicrofarads, T in centimeters, and S in square centimeters.

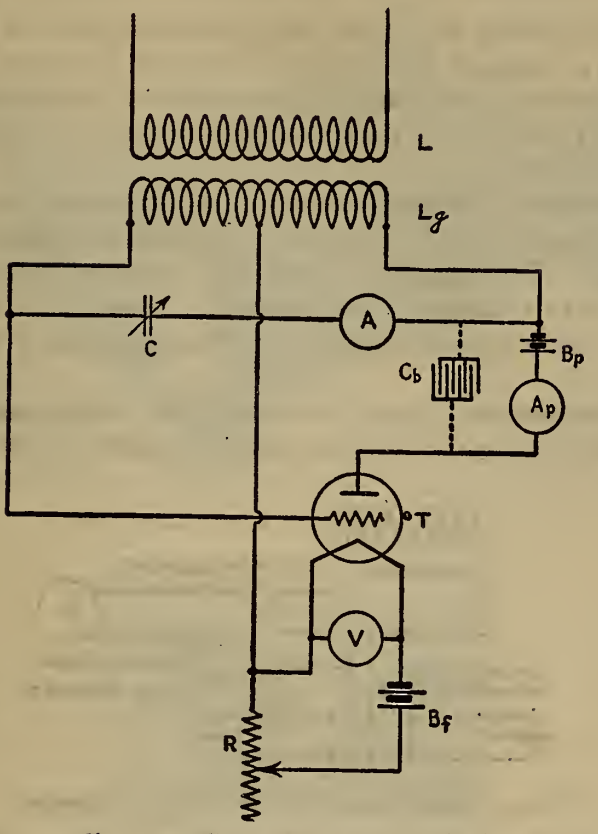

FIG. 4.—*Radio-frequency generating circuit.*

Circuits.—The measurement of phase difference and dielectric constant at radio frequencies requires a generating circuit and a suitable measuring circuit.

The generating circuit is shown schematically in Figure 4. The inductance coil L_g is any one of a series of detachable tubular single-layer inductors arranged somewhat as shown in Figure 5. For the range of frequencies generally used, it is probable that no more than 5 tubular inductors will be required. The smaller inductor may be made by winding 13 turns of wire on a 3½-inch tube with 6 turns on either

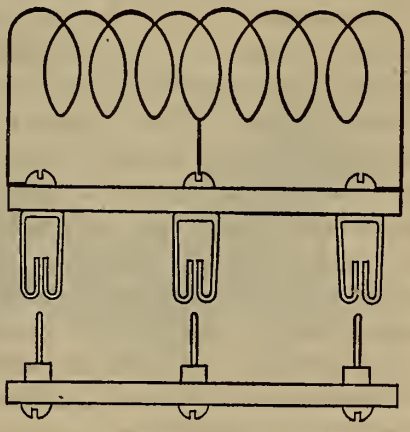

FIG. 5.—*Inductance coil used in generating circuit.*

side of the middle clip. The larger inductor may be made by winding 112 turns of wire on a 6¾-inch tube, 32 turns on either side of the middle clip and 24 turns outside of both outside clips. The other three inductors may be made to cover the gap between these two extremes.

The variable air condenser C may be of any suitable commercial shielded type having a maximum capacity of about 0.003 μf (3,000 μμf). The ammeter A is of the expansion type having a range of 0 to 1 ampere. The by-pass condenser C_b may be any type of fixed condenser capable of withstanding 500 volts (direct current).

The plate battery B_p may be a 100 to 600 volt storage battery of the lead-acid type having an ampere capacity of not less than

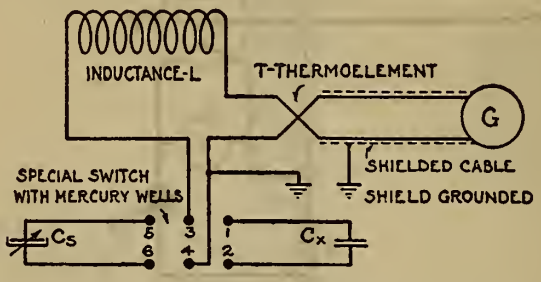

FIG. 7.—*Measuring circuit of phase-difference apparatus.*

0.2 ampere at the eight-hour discharge rate. Figure 6 shows a 100-volt unit of a battery of this type with the supports fixed for stacking the batteries in an upright position. A lead couple and jar are also shown separately in this figure.

The ammeter A_p may be any type of direct-current instrument having a range of 0 to 50 milliamperes. The three-electrode electron tube T may be any of the so-called power tubes rated at 5 watts or over. The voltmeter V may be any type of direct-current instrument having a range suited to the type of electron tube used. The filament battery B_f should be of the lead-acid type whose voltage and ampere-hour capacity will be determined by the type of electron tube selected. The ampere-carrying capacity and the resistance of the rheostat R would also be dependent on the type of tube selected.

The measuring circuit is shown schematically in Figure 7. The standard variable air condenser C_s may be of the Bureau of Standards standard type having a maximum capacity of not to

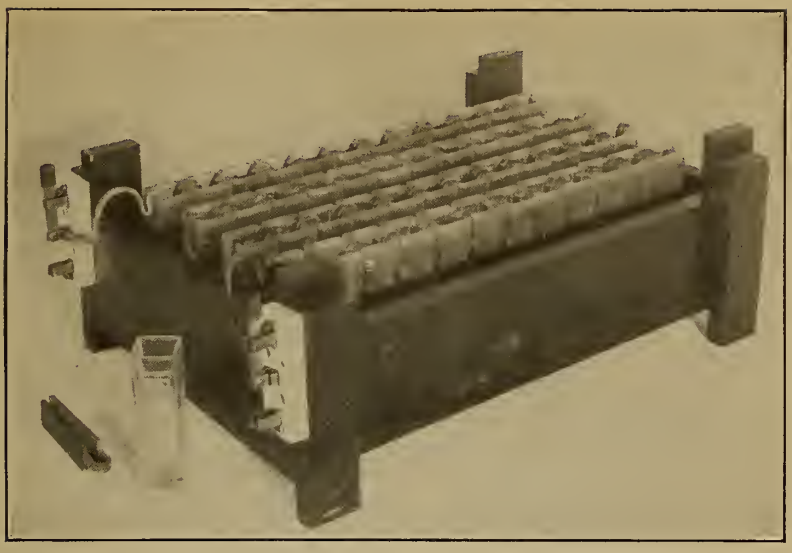

FIG. 6.—*One hundred volt unit of storage battery for plate circuit.*

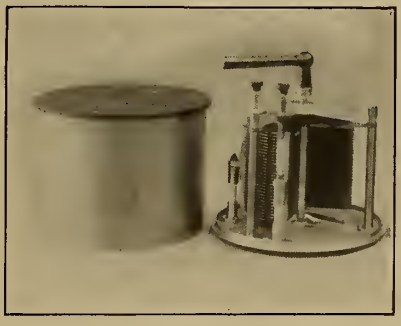

FIG. 8.—*Standard condenser used in measuring circuit.*

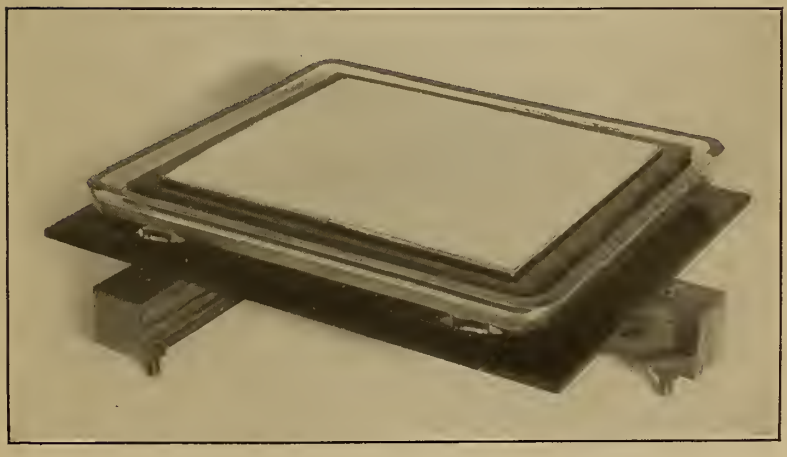

FIG. 10.—*Condenser with mercury plates and the test specimen as dielectric.*

FIG. 11.—*Inductance coil used in measuring circuit.*

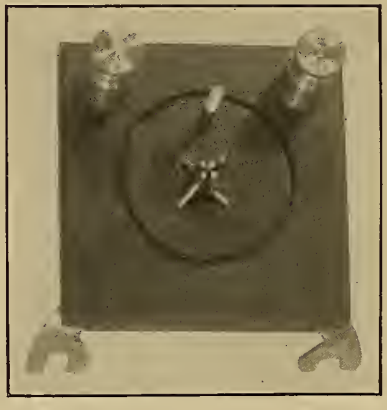

FIG. 12.—*Thermoelement used as current-measuring device.*

exceed 0.001 μf (1,000 μμf). Figure 8 shows the general construction of this type of condenser. This condenser is described more fully in Circular No. 74 of the Bureau of Standards, Radio Instruments and Measurements, section 32. The special switch with mercury wells, together with a noninductive resistor, are shown in Figure 9. The special switch is constructed throughout of insulating material except the leads and wells which are of copper. The two upright standards of the switch are Pyrex glass rods about 1 cm in diameter, while the supports which hold the six copper wells and leads are of Pyrex glass tubing. The copper wells are swaged to the copper leads and no solder used. The noninductive

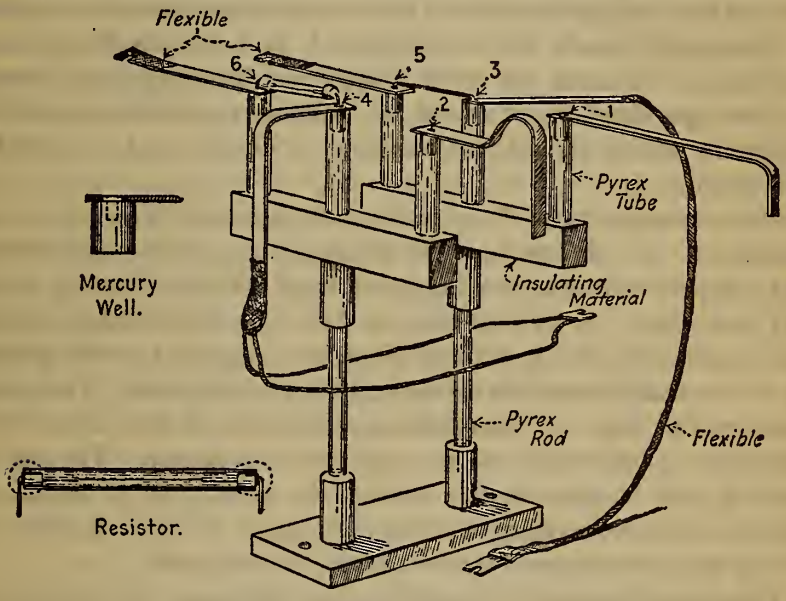

FIG. 9.—*Special switch in measuring circuit.*

resistor is made from a piece of glass tubing, two corks, two pieces of about No. 14 copper wire bent to form an L, and a piece of small-diameter, high-resistance wire. Several of these resistors are required, but in all cases the distance between the spurs should be the same, because the resistors must fit into the mercury wells, as shown in the switch (Fig. 9). Each of these units has a different value of resistance, made so by varying either the length or the diameter of the resistance wire, or both.

The condenser C_x is made by floating the sheet of insulating material or molded test specimen on mercury and pouring mercury on the upper surface until it is filled to the molded flange or

barriers placed on the sample. The mercury bath on which the specimen rests is contained in a glass dish which rests on a piece of insulating material, which in turn is supported by some sort of a leveling device. Figure 10 shows the method of floating the specimen (a rectangular specimen without a flange of the same material). A two-piece rectangular copper mercury retainer is used on the upper surface.

The standard inductor L, Figure 7, may be of the type shown in Figure 11, except that only standard binding posts will be required for connections. This inductor must be of some design having a comparatively low resistance, so that the coil resistance will not be a large proportion of the combined equivalent resistance of the circuit made up of inductor L and the specimen condenser C_x. To cover the wave frequencies (wave lengths) named in these specifications, it would be desirable to have at least five inductors having inductance values of about 0.1, 0.5, 1, 2, and 3 millihenries.

The thermoelement T is of the crossed-wire type shown in Figure 12. For this purpose the thermoelement base might better be equipped with four binding posts than with two binding posts and two clips. A cylindrical cap fits into the circular groove cut in the base and is held in place by a cap nut which screws on to the small brass bolt shown attached to the base. The wires used on this type of thermoelement may be of steel and "constantan" or "advance" about 0.02 mm in diameter. The resistance of the thermoelement should be from 3 to 5 ohms. A shielded cable connecting the thermoelement T to the galvanometer G may be standard lead-sheathed duplex cable.

The galvanometer G is a sensitive low-resistance wall galvanometer of the deflecting mirror type whose deflections within reasonable limits are proportional to the square of the current. A high-sensitivity galvanometer with an external damping resistance of about 5 ohms, period about two seconds and concave mirror for about 1 meter focal distance, has been found satisfactory.

Figure 13 shows the complete apparatus as assembled in the radio laboratory of the Bureau of Standards. For more exact measurements the complete apparatus itself is housed in a small section of the room and completely surrounded with a fine mesh wire, such as window screening. The purpose of this shielding is to insure the accuracy of measurement by shielding out the influence of outside radio-frequency generators. This view shows the wave meter mounted on a tall stand, a rather complicated

radio-frequency generator, a rack of 100-volt storage batteries, the bottle of distilled water for use with the batteries, the galvanometer rack showing the scale, lamp and galvanometer, the test specimen floated ready for measurement, the special skeleton switch, the standard inductor, the standard condenser, and a box of noninductive resistors. In addition there will be observed a series of parallel wires between the generating circuit and the measuring circuit and also between the measuring circuit and the place occupied by the operator. The parallel wires between the generating circuit and the measuring circuit are all soldered together at the end nearest the operator (the left-hand end, as shown) and left separate at the other end. The wire which connects all the parallel screening wires is then attached to a ground connection. The parallel wires between the measuring circuit and the operator are unattached at either end but all attached in the middle. This middle connector is also attached to the ground connection. The upper half of the shield between the operator and the measuring circuit is hinged to make it more easy to change the apparatus. It will be noticed that two panels of the over-all wire netting screen have been removed in the photograph. The third panel at the extreme right front of the photograph is hinged to form a door. This door permits the operator to arrange the test specimen in the mercury bath.

Method of measurement.—Assume that the 13-turn inductor L_g is in position as shown in Figure 4 and the other parts of the generating circuit are in readiness and generating radio-frequency current. Bring the generating circuit near to the measuring circuit with the shield of parallel wires between them, as shown in Figure 13. Put the 0.05-millihenry standard inductor L (Fig. 7) in position and insert heavy copper links between wells 1 and 3 and between 2 and 4. Write the value of the inductance L in space No. 1 of the data sheet, Table 1. Tune the generating circuit to the measuring circuit by varying the setting of the condenser C (Fig. 4), resonance being determined by the maximum deflection of the galvanometer G (Fig. 7). It is essential that this tuning be done carefully. Change the coupling between L_g and L (Fig. 4) until the maximum galvanometer deflection at resonance is about 40 cm if a 50-cm scale is used. Leave the generating circuit stand untouched and determine the wave frequency (wave length) emitted by the generating circuit by means of a frequency meter (wave meter). Record the wave-meter

setting in space No. 2, Table 1. Remove the wave meter. Remove the copper link on the grounded side (that is, between wells 2 and 4, Fig. 7) and read the zero of the galvanometer and record the value in column No. 1 of the data sheet. Reinsert the copper link and record the maximum deflection in column No. 2. Record the resistance of the heavy copper link as 0 in column No. 5. Remove the copper link spanning wells 2 and 4 and read the zero deflection of the galvanometer. Insert this as the second entry in column No. 1. Pick out a noninductive resistor of such resistance that it will cut the galvanometer deflection to about half the maximum value and insert between wells 2 and 4 to replace the copper link. Record the galvanometer deflection as a second entry in column No. 2 and the resistance of the resistor as a second entry in column No. 5. Assuming the copper link to be *A* and three noninductive resistors of increasing resistance values to be *B*, *C*, and *D*, insert the several links (*A*, *B*, *C*, and *D*) on the grounded side of the switch between wells 2 and 4 in the order, *AB*, *AC*, *AD*, *AC*, *AB*.

TABLE 1.—Sample of Record of Test.

Date of test ..... Specimen No. ..... Test No. ..... Specimen submitted by ..... No. submitted ..... Date ..... Filler ..... Binder ..... Grade ..... Color ..... Dry bulb, ..° C. ..° F. Wet bulb, ..° C. ..° F. Relative humidity .. per cent. Notes: .....

1. Standard inductance ..... mh.
2. Setting of wavemeter .....deg.
3. Setting of standard condenser ..... deg.
4. Identification number of standard condenser .....
5. Wave frequency ..... kc/s.
6. Wave length .....m.
7. Capacity of specimen .....μf.
8. Phase difference (ψ°) of specimen ..... deg.
9. Phase difference (ψ°) of circuit ..... deg.
10. Power factor of specimen ..... per cent.
11. Average thickness (T) of specimen ..... cm ..... in.
12. Area (S) of upper condenser plate ..... cm^2 ..... in.^{2}
13. Dielectric constant (K) .....

Galvanometer.				Resistance inserted R_1.	$\sqrt{\frac{d_0}{d_1}}-1$.	Total equivalent resistance, R.	Equivalent resistance of C_x., R_x.
Zero deflection.	Maximum deflection.	True deflection.	Mean deflection.				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0.30	41.70	41.40	41.40	A 0.....	.....	.....	22.08
.32	15.00	14.68	14.69	B 18.01.....	0.679	26.53	.....
.32	41.70	41.38	41.40	A 0.....	.....	.....	.....
.33	13.67	13.34	13.36	C 20.21.....	.761	26.56	.....
.33	41.70	41.37	41.37	A 0.....	.....	.....	.....
.38	12.81	12.43	12.43	D 21.84.....	.825	26.48	.....
.38	41.79	41.41	.....	A 0.....	.....	.....	.....
.36	13.75	13.39	.....	C 20.21.....	.....	Ave.	.....
.37	41.77	41.40	.....	A 0.....	.....	.....	.....
.39	15.09	14.70	.....	B 18.01.....	.....	26.52	.....
.49	41.71	41.22	41.23	A 0.....	.....	.....	.....
.52	17.35	16.83	16.84	B 2.51.....	.565	4.44	.....
.50	41.74	41.24	41.24	A 0.....	.....	.....	.....
.52	14.91	14.39	14.40	C 3.08.....	.692	4.45	.....
.50	41.77	41.27	41.27	A 0.....	.....	.....	.....
.52	11.42	10.90	10.90	D 4.20.....	.947	4.43	.....
.53	41.78	41.25	.....	A 0.....	.....	.....	.....
.53	14.93	14.40	.....	C 3.08.....	.....	Ave.	.....
.53	41.77	41.24	.....	A 0.....	.....	.....	.....
.55	17.39	16.84	.....	B 2.51.....	.....	4.44	.....

Record each zero and maximum deflection in the proper place in columns Nos. 1 and 2 and the value of resistance inserted in the circuit in column No. 5. Remove the links from the wells 1 to 3 and 2 to 4 and insert copper links between 3 and 5 and between 4 and 6. Move the generating circuit about 50 cm away from

the standard inductor L (Fig. 4), being careful not to change the setting of any of the variables in the generating circuit. Check the wave frequency of the generating circuit. Tune the measuring circuit (composed of the standard condenser C_s, standard inductor L, the thermoelement T and the galvanometer G) to the generating circuit by varying the setting of the standard condenser C_s. Change the coupling between L_g and L to give about 40 cm galvanometer deflection on the 50 cm scale. Tune the measuring circuit very carefully, but do not vary any controls on the generating circuit. Read the setting of the standard condenser C_s and record in space No. 3. If more than one standard condenser is available in the laboratory, record the number of the condenser used in space No. 4 for the purpose of identification. Remove the copper link from between wells 4 to 6, read the galvanometer zero deflection, and record the value in the first column of the data sheet. (See 0.49, column No. 1.) Reinsert the copper link and read the maximum galvanometer deflection,

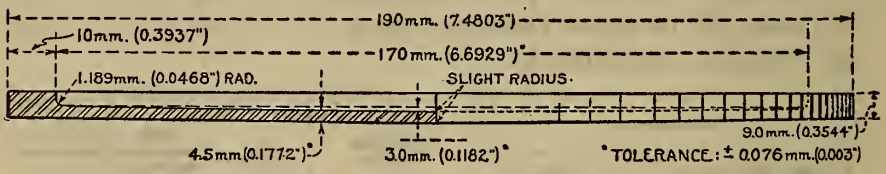

FIG. 14.—*Phase difference test specimen for molded materials.*

record the numerical value in column No. 2. Proceed in this manner, as above described, inserting resistors in the order AB, AC, AD, AC, AB.

The data in the body of the data sheet may now be computed. Column No. 3 is obtained by subtracting the zero deflection from the corresponding maximum deflection. Thus $41.70 - 0.30 = 41.40$, the true deflection, or $15.00 - 0.32 = 14.68$. Column No. 4 is obtained by averaging; that is, the two A deflections which precede the two B deflections, the two B deflections, the two A deflections which precede the two C deflections, and the two C deflections are averaged. Thus, the average of 41.40 and 41.40 is 41.40 and of 14.68 and 14.70 is 14.69. As has been stated, phase difference

$$\psi^\circ = 0.1079 \frac{RC}{\lambda}$$

The equivalent resistance R is computed in three steps and recorded in column No. 8. By one measurement the equivalent

resistance (R_x) of the condenser C_x plus the resistance (R_c) of the remainder of the circuit, including the inductor L, is determined. By another the equivalent resistance (R_s) of the standard condenser C_s and the resistance (R_c) of the remainder of the circuit, including the inductor L. Since in each case the remainder of the circuit is the same and the standard condenser C_s is considered to have negligible resistance, the difference of the resistance values will be the equivalent resistance of the specimen condenser C_x. That is, the resistance of the condenser C_x plus the resistance of the circuit is $R_x + R_c$, while the resistance of the standard condenser C_s plus the resistance of the circuit is $R_s + R_c$. R_s is negligible, so $R_s + R_c$ is equivalent to R_c. $(R_x + R_c) - R_c = R_x =$ the equivalent resistance of C_x.

The combined equivalent resistance of the specimen condenser and its attached circuit is computed first.

The equivalent resistance

$$R = \frac{R_1}{\sqrt{\frac{d_o}{d_1}} - 1}$$

where R_1 = resistance inserted,

d_1 = galvanometer deflection with R_1 inserted,

d_o = galvanometer deflection with no resistance inserted.

The denominator is solved first and its values inserted in column No. 6, while the values of R are inserted in column No. 7. Thus, the values in column No. 6 are

$$\sqrt{\frac{41.40}{14.69}} - 1 = 0.679, \sqrt{\frac{41.40}{13.36}} - 1 = 0.761, \text{ and } \sqrt{\frac{41.37}{12.43}} - 1 = 0.825$$

The equivalent resistance R (column No. 7) is obtained by dividing the ohmic resistance of the resistors B, C, and D by their respective denominators, as shown in the above equation. Thus, the values of R are

$$\frac{18.01}{0.679} = 26.53, \frac{20.21}{0.761} = 26.56, \frac{21.84}{0.825} = 26.48$$

The same procedure is followed to determine the resistance of $R_s + R_c$. As shown in the data sheet, these values are found to be 4.44, 4.45, and 4.43 ohms. The next step is to average each group of three resistances The equivalent resistance of the specimen condenser C_x is the difference between these averages, or $26.52 - 4.44 = 22.08$ ohms. The next step is to fill in spaces

Nos. 5, 6, and 7 by referring to the calibration charts of the wave meter and the standard condenser. With these values available, the phase difference, or power factor, of the specimen may be computed. As has been previously stated, phase difference expressed in degrees is

$$\psi^\circ = 3.60\, RCf \times 10^{-7}$$

or

$$= 0\ 1079\, \frac{RC}{\lambda}$$

Assuming the specimen capacity (C) to be 235 $\mu\mu$f, the wave frequency (f) to be 1,000 kilocycles per second (wave length 300 m), then the phase difference of the specimen is

$$\psi^\circ = 3.60 \times 22.08 \times 235 \times 1000 \times 10^{-7} = 1.87 \text{ deg.}$$

or

$$= \frac{0.1079 \times 22.08 \times 235}{300} = 1.87 \text{ deg.}$$

This value is inserted in space No. 8, while the phase difference of the circuit is computed and inserted in space No. 9. Thus, the phase difference of the circuit equals

$$3.60 \times 4.44 \times 235 \times 1000 \times 10^{-7} = 0.38 \text{ deg.}$$

or

$$\frac{0.1079 \times 4.44 \times 235}{300} = 0.38 \text{ deg.}$$

For the small values of phase difference usually found in the better types of electrical insulating material,

$$\text{Power factor in per cent} = 1.75 \times \psi^\circ$$

This quantity is computed and entered in space No. 10. The thickness and area of the specimen may now be measured and the values written in spaces Nos. 11 and 12, respectively. The thickness (T) should be the average of at least six micrometer readings. Having determined the thickness (T) and the area (S) and the capacity (C) (spaces Nos. 7, 11, and 12), the dielectric constant may be computed from the formula previously given. Assuming T and S to be 0.45 cm and 284 cm^2, respectively,

$$K = \frac{CT}{0.0885\, S} = \frac{235 \times 0.45}{0.0885 \times 284} = 4.2$$

The computed value of K is written in space No. 13. For the better comparison of electrical insulating materials for radio use

both the phase difference and the dielectric constant should be considered. Space No. 14 has been left for the numerical product of phase difference expressed in degrees and the dielectric constant. Thus,

$$\text{Product} = \psi^\circ K = 1.87 \times 4.2 = 7.86$$

TABLE 2.—Sample Report.[1]

Date of test, May 10, 1922. Specimen, No. 1.
Specimen submitted by A B C Co. Number submitted, 1. Date, May 1, 1922.
Filler, wood flour. Binder, X Y Z resin. Grade, No. 2. Color, natural.
Average thickness, 0.443 cm, 0.174 in. Room temperature, 21° C., 69.8° F.
Relative humidity, 54 per cent.

Wave frequency, f (kilocycles per second).	Wave length λ (meters).	Computed values.				Remarks.
		Phase difference ψ° (degree).	Power factor (per cent).	Dielectric constant, K.	Product of ψ° and K.	
1,071.0	280	2.04	3.57	5.20	10.6	As received.
492.0	610	1.92	3.36	5.28	10.1	
197.4	1,520	1.91	3.34	5.34	10.2	
113.6	2,640	1.86	3.25	5.37	10.0	
95.0	3,160	1.84	3.22	5.40	9.9	
1,027.0	292	2.12	3.71	5.40	11.4	After water treatment.
482.5	622	2.02	3.54	5.48	11.1	
195.5	1,534	2.01	3.52	5.54	11.1	
112.5	2,666	1.96	3.43	5.57	10.9	
93.8	3,200	1.94	3.39	5.60	10.9	

[1] The data in Tables 2 and 3 do not include any values computed in Table 1.

TABLE 3.—Sample Summary.

[Values of phase difference and dielectric constant at 300 and 3,000 m wave length as read from curves, Fig. 15.]

AS RECEIVED, AT 21° C.

Wave frequency, f.	Phase difference, ψ° (degrees).	Dielectric constant, K.	Product of ψ° and K.
100 kilocycles per second 3,000 m	1.84	5.39	9.92
1,000 kilocycles per second 300 m	2.02	5.21	10.53
Average	1.93	5.30	10.23

AFTER 48 HOURS IN WATER AT 21° C.

100 kilocycles per second 3,000 m	1.94	5.60	10.86
1,000 kilocycles per second 300 m	2.11	5.40	11.40
Average	2.02	5.50	11.13

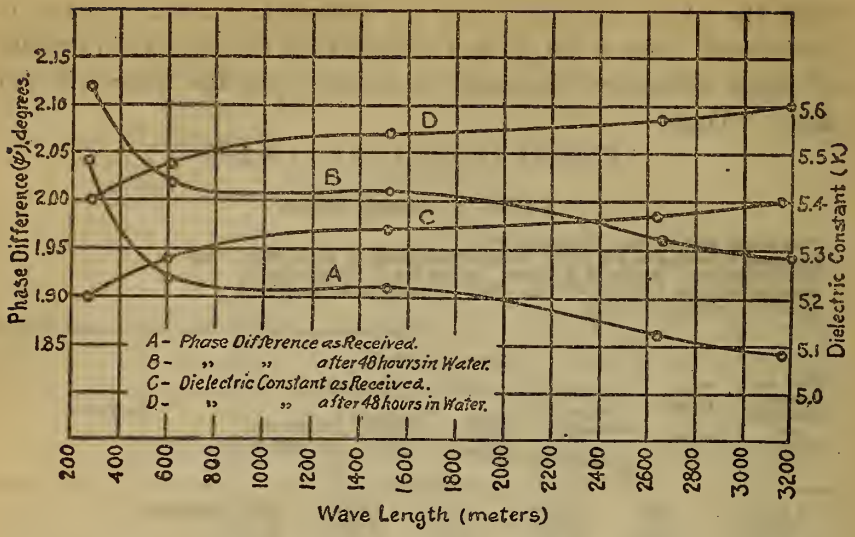

FIG. 15.—*Sample graphical data on phase difference and dielectric constant of molded phenolic insulating material at radio frequencies.*

III. VOLTAGE EFFECTS AT RADIO FREQUENCIES.

Arrangement of apparatus in high-voltage radio-frequency set.—Essentially, the method of measuring the effects of high voltages at radio frequencies is to place a sample of the material with electrodes upon its surface in parallel with a condenser in a radio circuit and measuring the radio-frequency voltage required to flash over the surface, break down the insulating specimen, or produce other effects. Figure 16 shows a photograph and Figure 17 a schematic diagram of the apparatus used to produce the high radio-frequency voltages.

In Figure 16 at *1* is shown the electron-tube cabinet containing six large electron tubes, necessary switches, rheostats, and ammeters. The electron tubes are so connected that any one or any number may be used in the circuit. The plates, grids, and filaments are all connected in parallel. The plate voltage is supplied by two 600-volt, 2.5-kw direct-current generators connected in series. At *2* is shown the inclosed switch in the 1,200-volt line to the plates. At *3* are shown three slide-wire rheostats for coarse adjustment of the plate voltage. The filament power is supplied by eight 8-volt, 100-ampere-hour storage batteries. The variable inductors shown at *4* (see also L_g and L_p, Fig. 17) have each about 40 microhenries of inductance at maximum setting. Five (*5*) shows a radio-frequency (hot wire) ammeter used for determining the effective voltage across the terminals of the large cylindrical copper condenser 7 of small capacity. This condenser

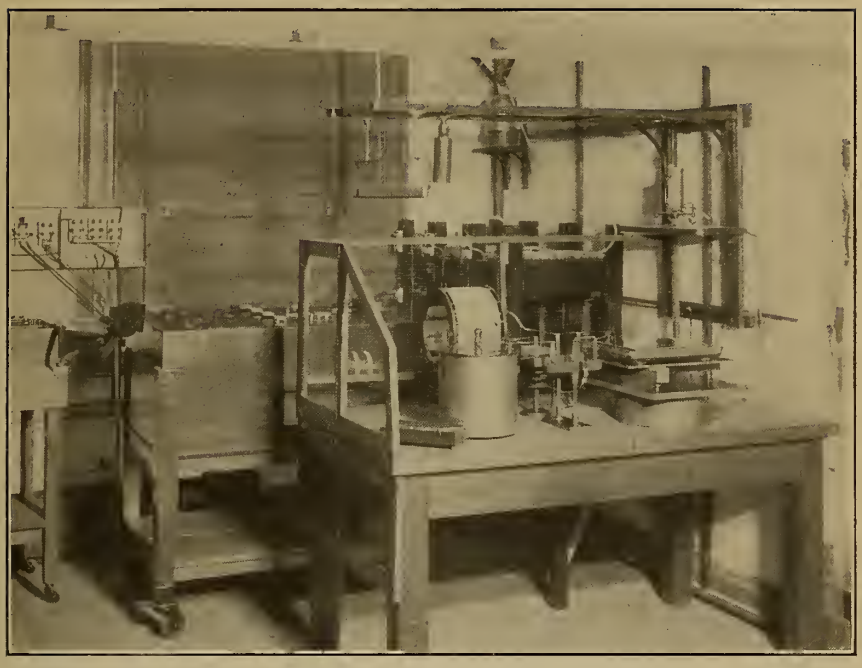

FIG. 13.—*General view of apparatus for measuring phase difference, the whole inclosed in metal screen.*

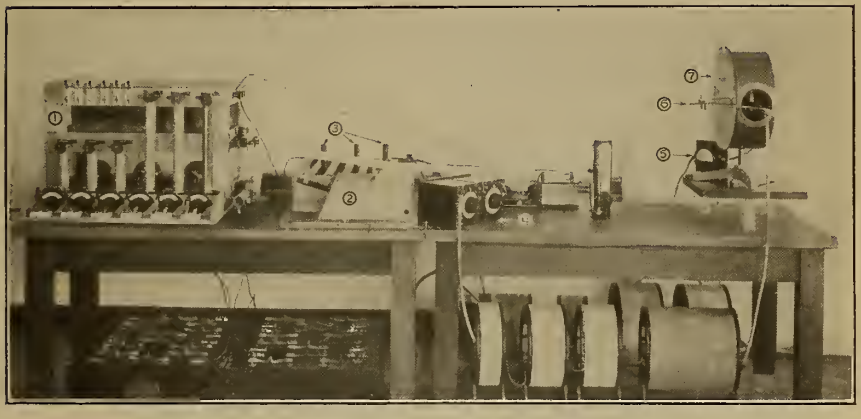

FIG. 16.—*Laboratory apparatus for generating 5,000 to 50,000 volts at about 100,000 cycles per second.*

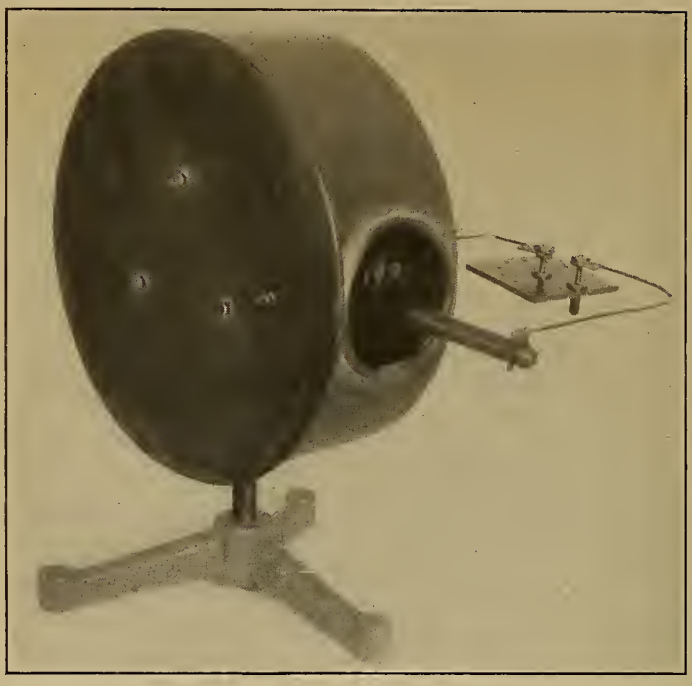

FIG. 18.—*Special low-capacity condenser for use in high-voltage radio-frequency generator, showing method of mounting the test sample.*

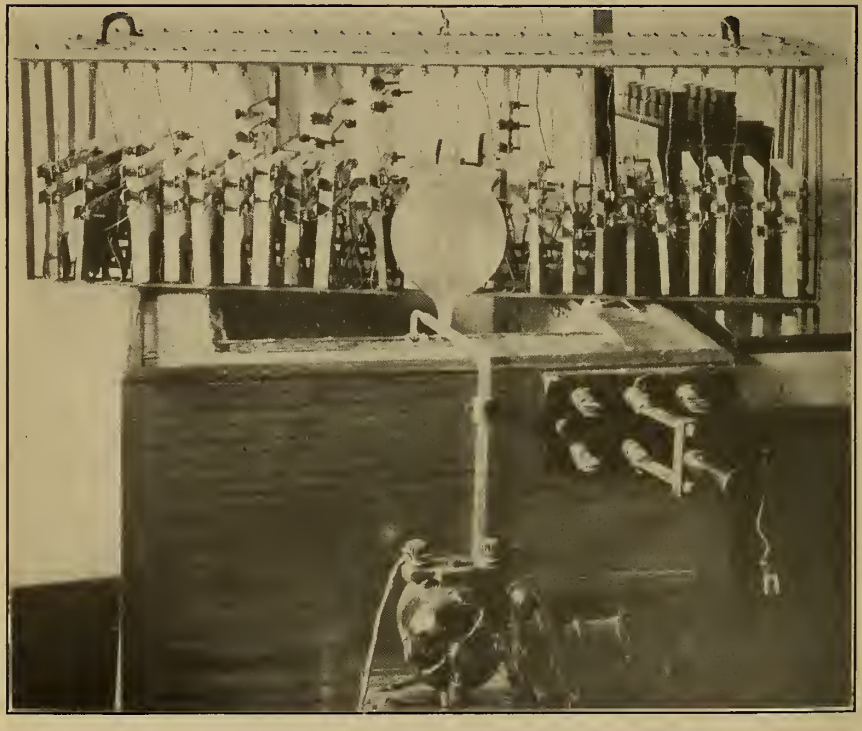

FIG. 20.—*Humidity control tank, showing arrangement of samples for surface resistivity measurement.*

(type R–41–A) has a circular disk of copper for the inner plate, the cylindrical container for the other plate, and air as the dielectric. All edges are finished with copper tubing to decrease the

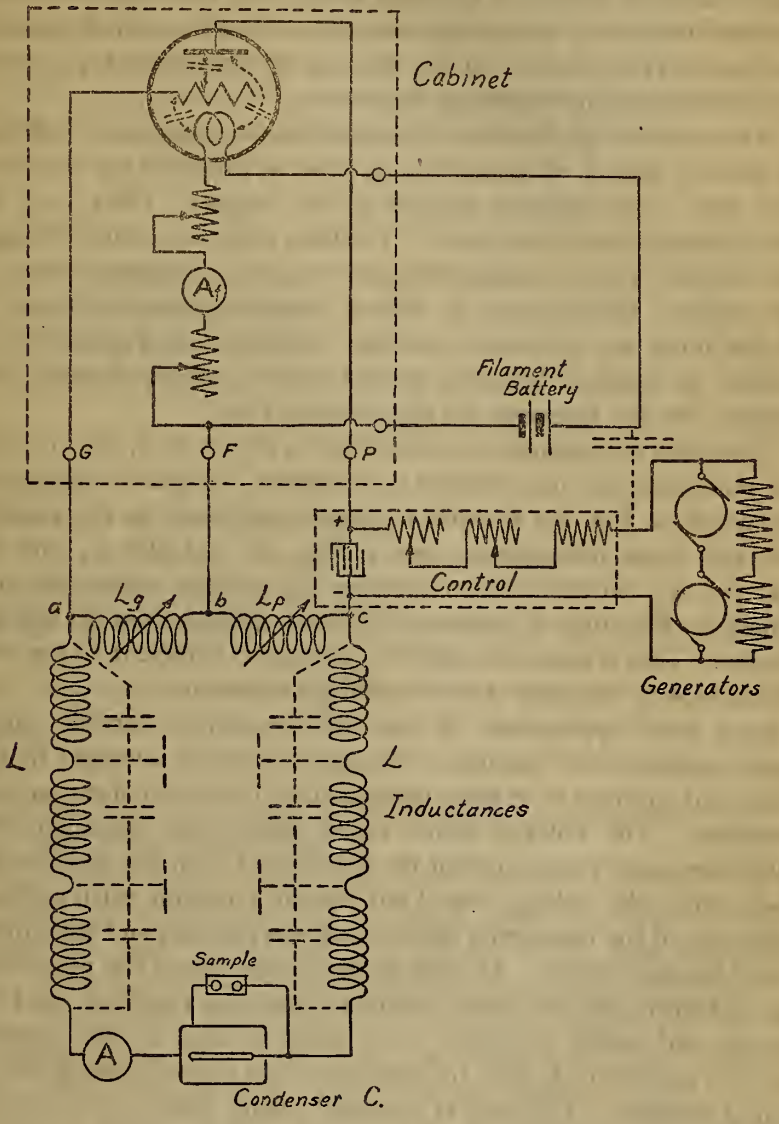

FIG. 17.—*Schematic diagram of apparatus for generating high voltages at radio frequencies and measuring their effects on insulating materials.*

possibility of corona or brush discharge. The inner plate is supported by three glass rods running through the outer plates. The capacity of the condenser is about 30 $\mu\mu$f. At *6* is shown a sample of insulating material, connected in parallel with the condenser,

in position for testing (see also Fig. 18). The inductance coils under the table have a total inductance of about 16 millihenries, divided so that there are 8 millihenries on the plate side of the circuit and the same on the grid side. The coils are wound on skeleton frames of insulating material of the laminated, phenol-methylene type, similar to the Bureau of Standards type standards [2] of inductance shown in Figure 11.

Measurement of flash-over voltage at radio frequencies.—Figure 18 shows a sample of insulating material as prepared for the flash-over test. The samples are cut 10 cm square. Only 0.64 cm thick samples have been used. Thirteen holes are drilled through the sample—12 at a radial distance of 4 cm, 30° apart, and 1 in the center. Each sample is drilled through a steel template, so all the holes are uniformly spaced. As shown in Figure 18, the voltage is applied between skirted studs passing through the sample, the gap between the skirts being 2 cm.

When the test sample is in position (as shown at *6*, Fig. 16) and the remainder of the circuit is in readiness, the plate voltage cut-off switch (*2*, Fig. 16) is rapidly opened and closed as the variable grid and plate inductances (see *4*, Fig. 16, and also L_g and L_p, Fig. 17) are varied so as to increase the voltage across the condenser (*7*, Fig. 16), or between the brass skirts bolted to the test sample. This is repeated until the voltage is sufficient to arc over the surface (2 cm gap) of the insulating material.

Such brief application of the high-frequency current causes little heating of the sample. Heating should be avoided in this particular method of getting comparative flash-over data on such materials. The voltage which exists across the specimen when flash-over takes place can not be determined with the specimen in place, since the voltage would not remain constant until a steady deflection of the measuring instrument was reached and the sample would become warm. As soon as discharge occurs the plate voltage is thrown off, all other controls remaining constant, and the sample and holder removed. The plate voltage is then applied, and the ammeter (*5*, Fig. 16) reading taken when a steady deflection is reached. This test is repeated, using holes 1, 3, 5, and 7, the other holes being reserved for check measurements on different days.

In making this measurement it should be noted that the wave length and capacity are both changed on removing the sample. The magnitude of the correction is small, however, as the two

[2] See Circular No. 74, p. 324, for description of inductance standards.

changes produce opposite effects on the computed voltage. It is also to be noted that the ammeter reading does not give the pure-capacity current just previous to the flash-over discharge, since in this condition the conductive component, owing to corona, may be considerable. These two components, however, are in quadrature, so that on good samples the error will be small.

The voltage produced across the terminals of a condenser in resonant circuit may be computed from the formula

$$E = \frac{I}{2 \pi f C} \tag{6}$$

where

I is the current through the condenser,

f is the frequency, and

C is the capacity of the condenser.

This formula may be put into the working form

$$E = \frac{530 \lambda I}{C}$$

where

λ is the wave length in meters,

C is the capacity in micromicrofarads and

E is volts when I is amperes.

Since the wave length (λ) and the capacity are practically constant as the setup is used $\frac{530 \lambda}{C}$ may be expressed as a constant k, then

$$E = k I \tag{7}$$

which means that by multiplying the ammeter reading by a constant the voltage is obtained.

Other voltage effects.—The flash-over voltage test is only one of a number of tests that may be made upon the effects of high voltage at radio frequencies. Among the other tests that have been made one of the most useful may be called an endurance test. In this test a voltage just below that necessary to arc the surface between the skirted studs (as determined by a previously made flash-over test) is applied to the sample. This voltage gradually drops, owing to electrical conduction and resultant heating of the sample. A record is made of the time elapsing until corona, flash-over, and blistering successively appear, as the voltage gradually drops to a value corresponding to an arbitrary ammeter reading, say, 0.3 ampere. The outer stud is moved to a hole in the test sample about 90° away. A somewhat lower

voltage is applied here and the time observed as above. Such tests are continued, using a lower voltage and a different hole each time. The final result is the highest voltage found, which when applied to the sample will remain constant for some specified time, such as 15 or 30 minutes, or which will just produce corona at the end of the specified time. The data collected in these endurance tests are complicated, require much space when tabulated, and are difficult to interpret. The method has not been perfected sufficiently to merit showing values in this paper.

Another high-voltage test is breakdown voltage. As in similar measurements at low frequencies, flat electrodes are applied to opposite surfaces of the sample and the voltage is raised until the material breaks down. The breakdown voltage depends on the rapidity with which the voltage is raised and is not nearly as definite a phenomenon as low-frequency puncture voltage. The breakdown is a most interesting phenomenon to observe. Cracks form, sparks creep along the surface adjacent to the electrodes in fascinating fashion, the material swells, blisters, and chars.

IV. ELECTRICAL RESISTIVITIES.

A full discussion of the measurement of insulation resistance of solid dielectrics is given in Scientific Paper of the Bureau of Standards No. 234, and hence the method need only be briefly abstracted here. Both volume resistivity and surface resistivity are calculated from measurements of electrical resistance and dimensions. For information on the separate calculation of the two resistivities when both affect the results see the paper just referred to. The discussion here deals with the most important measurement involved, that of resistance.

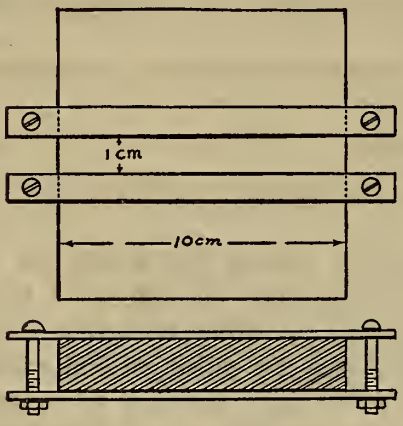

FIG. 19.—*Specimen arranged with metal clamps to measure surface resistivity.*

For measuring the surface resistivity or leakage over the surface it has been found most convenient to cut the specimens into plates 10 cm square. The surfaces are then carefully cleaned with a dry cloth to remove possible conducting particles. Metal strips 1 cm wide are clamped to these with their adjacent edges 1 cm apart, as shown in Figure 19. To insure good contact, tin

foil is wrapped around the metal strips and carefully pressed against the surface of the insulator along the inside edge of each strip. For determining the effect of temperature and humidity it is necessary to place the samples in a case, the temperature and humidity of which can be maintained constant. The temperature is maintained constant at about 26° C. by a vapor-pressure thermostat. The humidity is regulated by placing in the case an open vessel containing a sulphuric acid solution of the proper strength to give the desired humidity. The air is thoroughly

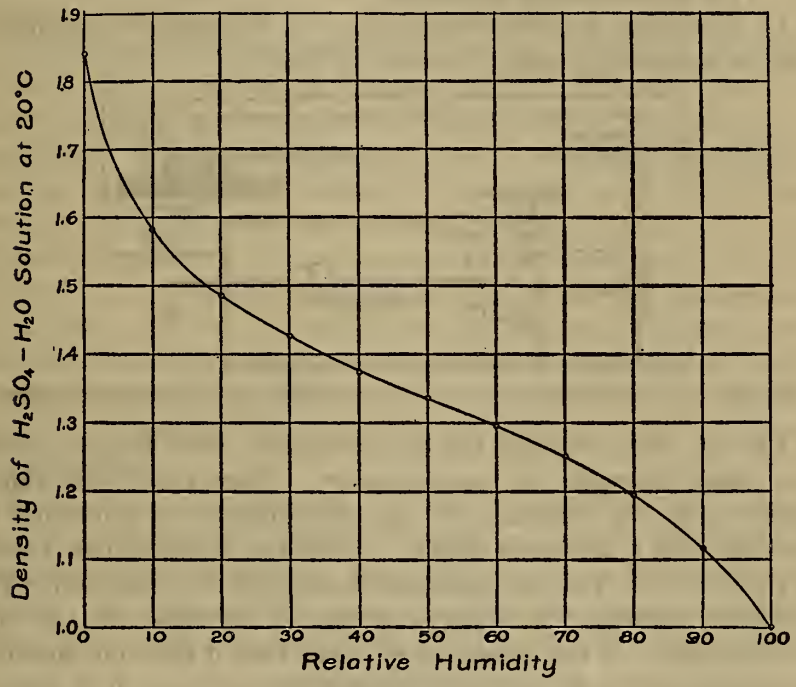

FIG. 21.—*Graph showing the relation between the density of a sulphuric-acid solution and the relative humidity which will be maintained by it in an inclosure.*

stirred by a fan, the driving motor being outside the case. The leads to the specimens are brought out through paraffin on the top of the case. The tray holding the specimens is sealed into the case with paraffin, making an air-tight container. The arrangement of the specimens in the case is shown in Figure 20.

The acid solutions are chosen of such densities so as to give relative humidities of 25 or 34, 50, and 85 per cent (see Fig. 21), and the specimens are allowed to remain in the case, exposed to the particular humidity desired for at least 24 hours before tests are made.

The diagram (Fig. 22) shows the method used for measuring high resistance, particularly adapted here for measuring the volume resistivity of a specimen.

The terminal (F) of the battery is connected to the mercury on which the specimen floats. The current flows through the specimen to the mercury contained in an open cylinder of known area which is connected to D. To prevent the current which flows over the surface of the specimen from reaching D, a guard ring of mercury surrounds the inner cylinder but is insulated from it. This guard ring is grounded.

In measuring a surface resistance, the resistance to be measured is connected directly between D and F.

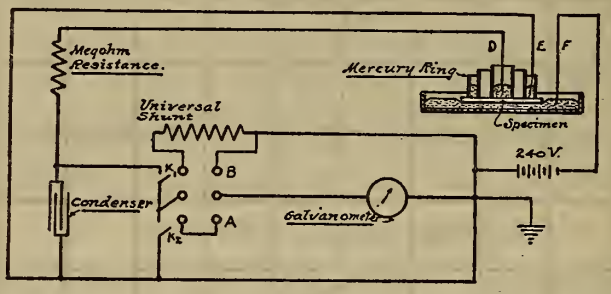

FIG. 22.—*Connections for measuring volume resistivity by the galvanometer method.*

Key K_2 short circuits the galvanometer, while key K_1 closes the circuit through the galvanometer. When the double-throw switch is in the direction B, the galvanometer is connected in parallel with a universal shunt. When the double-throw switch is thrown to A, the galvanometer is connected in series with the specimen without the damping resistance contained in the universal shunt. If the current is so small that it does not produce an appreciable deflection upon closing the key (K_1), it is opened so that the current flowing through the specimen will charge the condenser. At the end of a time (t) the key (K_1) is again closed and the charge which has accumulated is discharged through the galvanometer. From the ballistic constant of the galvanometer the resistance of the specimen may be computed as follows:

$$R = \frac{Et}{Kd} \tag{8}$$

where

t = time in seconds of charging the condenser,
E = impressed emf,
K = ballistic constant of the galvanometer,
d = deflection.

V. MECHANICAL PROPERTIES.

1. DENSITY AND MOISTURE ABSORPTION.

Density values are obtained by observations of weight in air and in water at room temperature. The same samples are used for determining density as for moisture absorption. These samples are cut 5 by 10 cm by the thickness of the material and totally submerged in water at room temperature for 24 hours. They are then removed and wiped carefully with a clean cloth to remove the unabsorbed surface film of water and reweighed at once. The original weight in air is taken as 100 per cent.

It is impossible to compare the percentage of moisture absorbed by two different samples of the same grade or different grades of insulating material if samples of different sizes or thicknesses are considered. Since moisture absorption is a surface phenomenon, one can not compare percentage values based on weights when surface does not increase in the same ratio as weight. The total surface areas of 5 by 10 cm by 0.635 and 1.27 cm samples are in the ratio of 119 to 138, while the weights of the two samples are in the ratio of 1 to 2. Furthermore, in tests of laminated materials, the percentage change in weight owing to absorption varies with any change of dimensions of sample because of the different rates of moisture absorption at the cut surfaces and at the fabricated surfaces.

In future measurements it is planned to determine the rate of moisture absorption in grams of water per square centimeter of insulating material surface. Such data would be independent of sample, size, and weight. This necessitates separate measurements of absorption at the cut edge and at the fabricated surface.

2. TENSILE STRENGTH.

All measurements of tensile strength of insulating materials were made on an Olsen testing machine of 20,000 pounds capacity. The first tests were made, using the regular wedge friction jaws, which did not permit self-alignment of the perpendicular axis of the sample with the line of stress. This method of procedure was unsatisfactory, and later wedges were used in the jaws to give flexibility along the plane parallel to the plane of lamination of the sample. Samples of standard design No. 1 (Fig. 23) were used. It was impossible at the time to design and construct ball-and-socket jaws that would render the alignment of the test sample free and automatic. In view of this fact, it was decided to try design No. 2 (Fig. 23), which was not held by rigid jaws at all. A special adapter was used which consisted of a U-shaped piece

of steel with a hole near the end of either leg. The end of the test specimen was secured to the adapter by a steel pin, which was passed laterally through the holes in the legs of the adapter and the hole in the end of the specimen. This type gave all desired flexibility, but had the disadvantage that to maintain the same cross-sectional area in the reduced section the width of the ends of the sample had to be increased from 1 to 2½ inches, so that the fracture would come in the reduced section instead of near the hole in the specimen. This type of sample not only required more insulating material, but also required much more time to prepare. Particular care had to be used to bring the line of centers of the holes in line with the line of center of the reduced section.

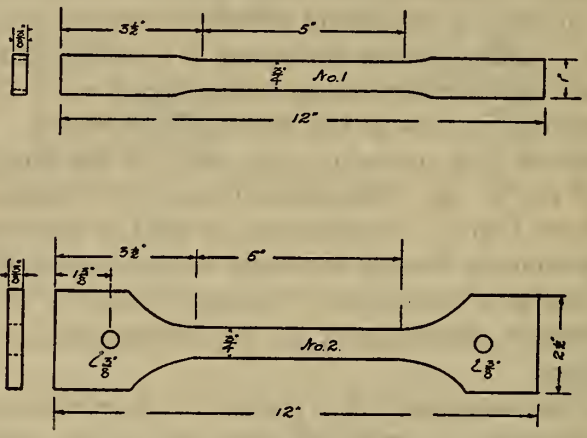

FIG. 23.—*Diagrams of machined tensile strength specimens.*
Specimen No. 1 tested in friction jaws; specimen No. 2 tested with clevis and bolt.

Care was used in properly aligning the perpendicular axis of the sample as tested with the line of stress. The tests made on samples, type 2, gave no data inconsistent with the other data found by using the semirigid jaws. There are variations from sample to sample cut from the same sheet which are greater than the effects of the different types (1 and 2, Fig. 23) of samples and jaws. The variation of tensile-strength values found in laminated phenolic materials by either method of testing can be attributed largely to the effect of grain of the paper. Since it is practically impossible for the consumer to determine the grain of the insulating material by the appearance, there is little use in giving mechanical data for mechanical purposes that is more accurate than a material's uniformity.

Before any thorough research of the effect of pressure, time of curing, percentage of varnish, grain of paper, etc., would be attempted, gripping jaws would be fitted with ball-and-socket

joints to allow for perfect, automatic alignment of the perpendicular axis of the sample with the line of stress. This would eliminate any possible doubt as to error introduced by improper alignment. There is also a possibility that the element of the sample crushing in the jaws contributes its share of trouble.

When data on the modulus of elasticity of the insulating material were desired, an extensometer was used and the elongation observed between gage marks placed 2 inches apart. The extension between 2-inch gage marks is negligible. There is considerable danger of injury to a delicate extensometer, as it is likely to be broken when the sample breaks.

3. TRANSVERSE STRENGTH.

Measurements of transverse strength of insulating materials were made on samples 12 inches long and 1 inch wide. The sam-

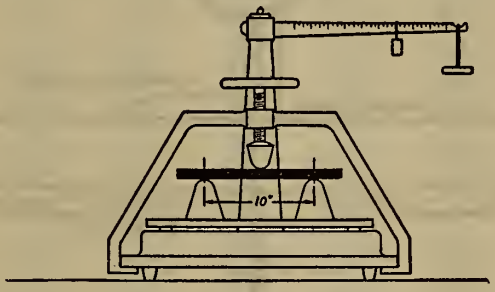

FIG. 24.—*Method of making transverse strength tests, using a platform balance.* The stress as recorded on the beam is dependent on the yield of the sample.

ples were supported by two V blocks placed 10 inches apart. The load (P) was applied at the center of the sample by a screw press over a platform balance or by suspending weights. The deflection (f) at the center was measured by an Ames dial or by other suitable methods. The two methods of loading the test sample are shown by Figures 24 and 25.

4. HARDNESS.

The method of making hardness measurements needs little description, for the Brinell and Shore scleroscope methods are quite well known.

The Brinell hardness numerals (abbreviated Bhn.) were determined on an Alpha Brinell hardness testing machine. The mechanical principle of this machine is practically the same as the American made machines. The sample to be tested is put on the solid stage plate, and the stage plate raised until the sample touches the vertical steel plunger, in the lower end of which is fitted a hardened steel ball, 10 mm in diameter. A force of 500

kg is exerted downward on the plunger for 30 seconds and then released. The steel ball imbeds itself in the insulating material to a depth depending upon the relative hardness of the material. A Brinell hardness numeral expresses a ratio of pressure applied to area of spherical indentation. This ratio may be found by measuring the depth of the indentation t or the diameter of the indentation d. The latter method has been used in the data given in this report because recent investigations have shown that this method gives more reliable data.

Some measurements of hardness were made by the Brinell method, using 250 kg because the samples had been previously

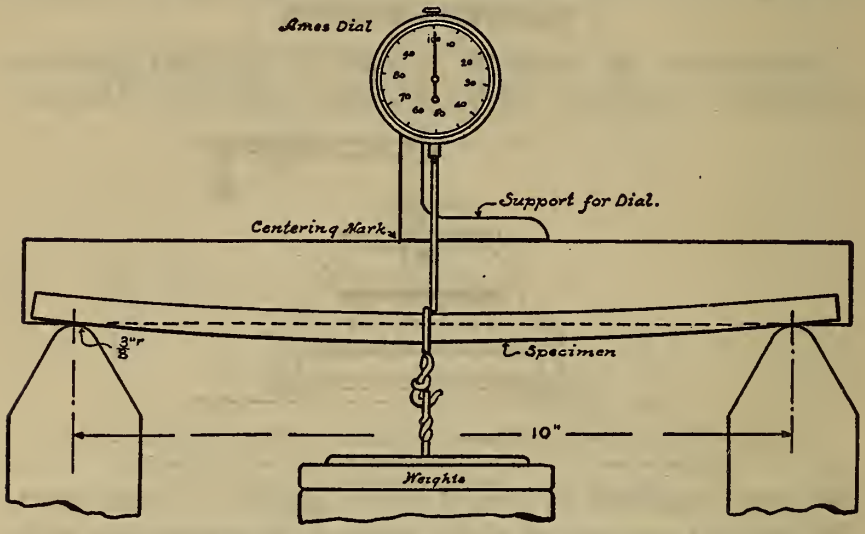

FIG. 25.—*Method of making transverse strength tests, using a dead weight.*

subjected to a sodium hydroxide solution which rendered the material too soft for 500 kg pressure.

It seems well to give some general statements here in regard to Brinell hardness numerals (Bhn.). The numerals are a function of the pressure as well as of the material. If two materials are tested, one material using 500 kg pressure, one other material using 250 kg, and the ratio of the Bhn. by the two methods is 2 to 1, it does not follow that two other materials tested at these same pressures would show the same ratio of 2 to 1. Also a material that has a hardness of 60 can not be said to be twice as hard as one whose hardness is 30. (See p. 65 for the relation of diameter of indentation to hardness numeral.)

The Shore scleroscope method is described sufficiently under definitions of mechanical properties, page 521, B. S. Technologic Papers No. 216.

TABLE 4.—Brinell Hardness Numerals at 500 kg Pressure.

Diameter indentation.	Brinell hardnesa numerals.	Diameter indentation.	Brinell hardness numerals.	Diameter indentation.	Brinell hardness numerals.	Diameter indentation.	Brinell hardness numerals.
mm		mm		mm		mm	
2.00	158	2.65	89	3.30	57	3.95	39
2.01	156	2.66	88	3.31	57	3.96	39
2.02	155	2.67	88	3.32	56	3.97	39
2.03	153	2.68	87	3.33	56	3.98	38
2.04	152	2.69	87	3.34	55	3.99	38
2.05	150	2.70	86	3.35	55	4.00	38.0
2.06	149	2.71	85	3.36	55	4.01	37.8
2.07	147	2.72	85	3.37	55	4.02	37.6
2.08	146	2.73	84	3.38	54	4.03	37.4
2.09	144	2.74	84	3.39	54	4.04	37.2
2.10	143	2.75	83	3.40	54	4.05	37.0
2.11	142	2.76	82	3.41	54	4.06	36.8
2.12	140	2.77	82	3.42	53	4.07	36.6
2.13	139	2.78	81	3.43	53	4.08	36.4
2.14	137	2.79	81	3.44	52	4.09	36.2
2.15	136	2.80	80	3.45	52	4.10	36.0
2.16	135	2.81	79	3.46	52	4.11	35.8
2.17	134	2.82	79	3.47	51	4.12	35.6
2.18	132	2.83	78	3.48	51	4.13	35.4
2.19	131	2.84	78	3.49	50	4.14	35.2
2.20	130	2.85	77	3.50	50	4.15	35.0
2.21	129	2.86	76	3.51	50	4.16	34.9
2.22	128	2.87	76	3.52	50	4.17	34.8
2.23	126	2.88	75	3.53	49	4.18	34.7
2.24	125	2.89	75	3.54	49	4.19	34.6
2.25	124	2.90	7_4	3.55	49	4.20	34.5
2.26	123	2.91	7_4	3.56	49	4.21	34.3
2.27	122	2.92	7_4	3.57	49	4.22	34.1
2.28	121	2.93	7_3	3.58	48	4.23	34.0
2.29	120	2.94	7_3	3.59	48	4.24	33.8
2.30	119	2.95	73	3.60	48	4.25	33.6
2.31	118	2.96	72	3.61	48	4.26	33.4
2.32	117	2.97	72	3.62	47	4.27	33.2
2.33	116	2.98	71	3.63	47	4.28	33.0
2.34	115	2.99	71	3.64	46	4.29	32.8
2.35	114	3.00	70	3.65	46	4.30	32.6
2.36	113	3.01	69	3.66	46	4.31	32.5
2.37	112	3.02	69	3.67	46	4.32	32.4
2.38	111	3.03	68	3.68	45	4.33	32.2
2.39	110	3.04	68	3.69	45	4.34	32.1
2.40	109	3.05	67	3.70	45	4.35	32.0
2.41	108	3.06	67	3.71	45	4.36	31.8
2.42	107	3.07	66	3.72	45	4.37	31.7
2.43	107	3.08	65	3.73	44	4.38	31.5
2.44	106	3.09	65	3.74	44	4.39	31.4
2.45	105	3.10	65	3.75	44	4.40	31.2
2.46	104	3.11	65	3.76	44	4.41	31.0
2.47	103	3.12	64	3.77	44	4.42	30.9
2.48	102	3.13	64	3.78	43	4.43	30.7
2.49	101	3.14	63	3.79	43	4.44	30.6
2.50	100	3.15	63	3.80	43	4.45	30.4
2.51	99	3.16	63	3.81	43	4.46	30.3
2.52	98	3.17	62	3.82	42	4.47	30.1
2.53	98	3.18	62	3.83	42	4.48	30.0
2.54	97	3.19	61	3.84	41	4.49	29.8
2.55	96	3.20	61	3.85	41	4.50	29.7
2.56	95	3.21	61	3.86	41	4.51	29.6
2.57	95	3.22	60	3.87	41	4.52	29.5
2.58	94	3.23	60	3.88	40	4.53	29.3
2.59	94	3.24	59	3.89	40	4.54	29.2
2.60	93	3.25	59	3.90	40	4.55	29.1
2.61	92	3.26	59	3.91	40	4.56	29.0
2.62	91	3.27	58	3.92	40	4.57	28.8
2.63	91	3.28	58	3.93	39	4.58	28.7
2.64	90	3.29	57	3.94	39	4.59	28.5

TABLE 4.—Brinell Hardness Numerals at 500 kg Pressure—Continued.

Diameter indentation.	Brinell hardness numerals.	Diameter indentation.	Brinell hardness numerals.	Diameter indentation.	Brinell hardness numerals.	Diameter indentation.	Brinell hardness numerals.
mm		mm		mm		mm	
4.60	28.4	5.20	21.8	5.80	17.2	6.40	13.8
4.61	28.3	5.21	21.7	5.81	17.1	6.41	13.7
4.62	28.2	5.22	21.7	5.82	17.1	6.42	13.7
4.63	28.0	5.23	21.6	5.83	17.0	6.43	13.6
4.64	27.9	5.24	21.6	5.84	17.0	6.44	13.6
4.65	27.8	5.25	21.5	5.85	16.9	6.45	13.5
4.66	27.7	5.26	21.4	5.86	16.8	6.46	13.5
4.67	27.6	5.27	21.3	5.87	16.8	6.47	13.4
4.68	27.4	5.28	21.2	5.88	16.7	6.48	13.4
4.69	27.3	5.29	21.1	5.89	16.7	6.49	13.3
4.70	27.2	5.30	21.0	5.90	16.6	6.50	13.3
4.71	27.1	5.31	20.9	5.91	16.5	6.51	13.3
4.72	26.9	5.32	20.8	5.92	16.4	6.52	13.2
4.73	26.8	5.33	20.8	5.93	16.4	6.53	13.2
4.74	26.6	5.34	20.7	5.94	16.3	6.54	13.1
4.75	26.5	5.35	20.6	5.95	16.2	6.55	13.1
4.76	26.4	5.36	20.5	5.96	16.1	6.56	13.0
4.77	26.3	5.37	20.4	5.97	16.1	6.57	13.0
4.78	26.1	5.38	20.3	5.98	16.0	6.58	12.9
4.79	26.0	5.39	20.2	5.99	16.0	6.59	12.9
4.80	25.9	5.40	20.1	6.00	15.9	6.60	12.8
4.81	25.8	5.41	20.0	6.01	15.8	6.61	12.8
4.82	25.7	5.42	19.9	6.02	15.8	6.62	12.7
4.83	25.6	5.43	19.9	6.03	15.7	6.63	12.7
4.84	25.5	5.44	19.8	6.04	15.7	6.64	12.6
4.85	25.4	5.45	19.7	6.05	15.6	6.65	12.6
4.86	25.3	5.46	19.6	6.06	15.5	6.66	12.6
4.87	25.2	5.47	19.5	6.07	15.5	6.67	12.5
4.88	25.1	5.48	19.5	6.08	15.4	6.68	12.5
4.89	25.0	5.49	19.4	6.09	15.4	6.69	12.4
4.90	24.9	5.50	19.3	6.10	15.3	6.70	12.4
4.91	24.8	5.51	19.2	6.11	15.3	6.71	12.4
4.92	24.7	5.52	19.2	6.12	15.2	6.72	12.3
4.93	24.6	5.53	19.1	6.13	15.2	6.73	12.3
4.94	24.5	5.54	19.1	6.14	15.1	6.74	12.2
4.95	24.4	5.55	19.0	6.15	15.1	6.75	12.2
4.96	24.3	5.56	18.9	6.16	15.0	6.76	12.1
4.97	24.2	5.57	18.8	6.17	15.0	6.77	12.0
4.98	24.0	5.58	18.8	6.18	14.9	6.78	12.0
4.99	23.9	5.59	18.7	6.19	14.9	6.79	11.9
5.00	23.8	5.60	18.6	6.20	14.8	6.80	11.9
5.01	23.7	5.61	18.5	6.21	14.7	6.81	11.9
5.02	23.6	5.62	18.4	6.22	14.7	6.82	11.8
5.03	23.5	5.63	18.4	6.23	14.6	6.83	11.8
5.04	23.4	5.64	18.3	6.24	14.6	6.84	11.7
5.05	23.4	5.65	18.2	6.25	14.5	6.85	11.7
5.06	23.2	5.66	18.1	6.26	14.5	6.86	11.7
5.07	23.1	5.67	18.0	6.27	14.4	6.87	11.6
5.08	23.0	5.68	18.0	6.28	14.4	6.88	11.6
5.09	22.9	5.69	17.9	6.29	14.3	6.89	11.5
5.10	22.8	5.70	17.8	6.30	14.3	6.90	11.5
5.11	22.7	5.71	17.7	6.31	14.2	6.91	11.5
5.12	22.6	5.72	17.7	6.32	14.2	6.92	11.4
5.13	22.5	5.73	17.6	6.33	14.1	6.93	11.4
5.14	22.4	5.74	17.6	6.34	14.1	6.94	11.3
5.15	22.3	5.75	17.5	6.35	14.0		
5.16	22.2	5.76	17.4	6.36	14.0		
5.17	22.1	5.77	17.4	6.37	13.9		
5.18	22.0	5.78	17.3	6.38	13.9		
5.19	21.9	5.79	17.3	6.39	13.8		

5. FORMULAS FOR COMPUTING MECHANICAL PROPERTIES.

$$\text{Percentage moisture absorption} = \frac{W_2 - W_1}{W_1} \times 100 \text{ per cent}$$

where W_1 = weight before water treatment

W_2 = weight after water treatment

$$\text{Ultimate strength (tensile)} = \frac{P}{bd} \tag{9}$$

$$\text{Modulus of elasticity (tensile)} = \frac{PL}{bdl} \tag{10}$$

$$\text{Modulus of rupture} = \frac{3PL}{2bd^2} \tag{11}$$

$$\text{Modulus of elasticity (transverse)} = \frac{L^2S}{6df} = \frac{PL^3}{4bd^3f} \tag{12}$$

where P = load, in pounds

b = width of sample at place of rupture, in inches

d = thickness of sample, in inches

L = original distance between gage marks (tensile) = length of span (transverse), in inches

l = elongation between gage marks

S = extreme fiber stress in lbs./in.^{2} (modulus of rupture)

f = deflection at center

Brinell hardness numeral $= P \div \pi\, tD$

$$= P \div \left[\pi D\left(\frac{D}{2} - \sqrt{\frac{D^2}{4} - \frac{d^2}{4}}\right)\right] \tag{13}$$

where P = pressure

t = depth of indentation

D = diameter of ball

d = diameter of indentation

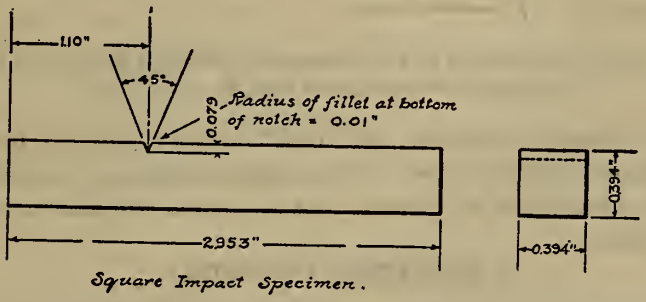

FIG. 26.—*Details of specimen used to determine resistance to impact.*

6. IMPACT STRENGTH.

6. Tests of resistance to impact were made on standard samples of the shape shown by Figure 26. The long end of a sample is

placed in a rigid vise with the apex of the slot parallel to the vise jaws and on a level with the upper edges of the jaws. A pendulum hammer is hung above the line of center of the sample, then pulled back a certain angular distance and released. The hammer strikes the sample on the short end of the slotted face, breaks it off, and swings past the position of equilibrium. The angular distance the hammer swings past the position of equilibrium is subtracted from the initial distance. From this, with other data, is computed the energy absorbed in producing rup-

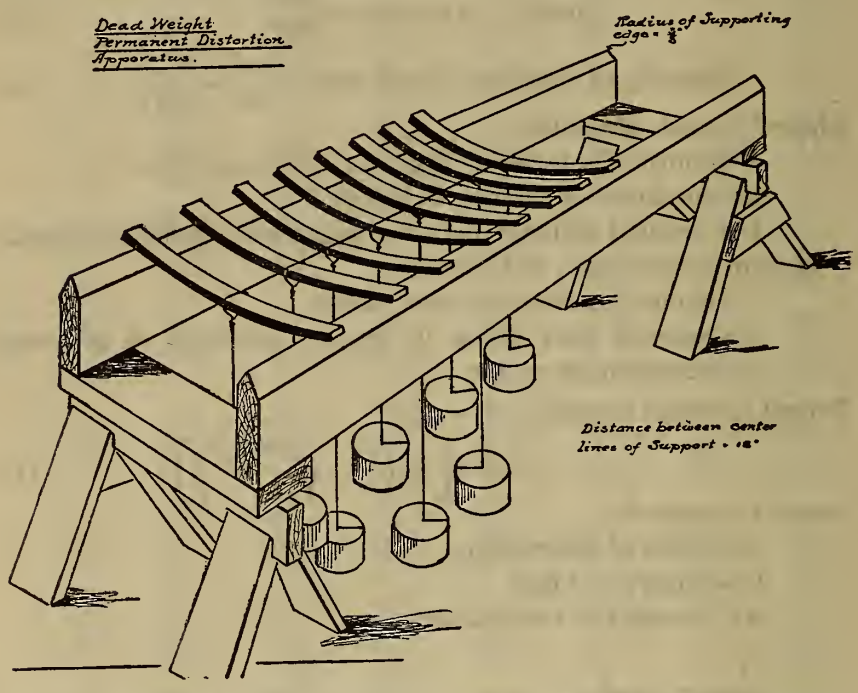

FIG. 27.—*Improvised apparatus used to determine the permanent distortion of sag caused by the application of different loads for a given time.*

ture. In general, however, all impact strength testing machines are calibrated and equipped with an index showing the number of foot-pounds of work equivalent to the various angular settings of the pendulum.

7. PERMAMENT DISTORTION.

The apparatus that was developed for permanent distortion tests is illustrated by Figure 27. Dead loads are applied at the center of span of each specimen. The span in all cases was 12 inches. After the specimen has been so loaded for 24 hours the load is removed. After allowing an additional 24 hours for

the recovery of the specimen the permanent distortion is measured in a manner similar to the illustration, Figure 25. The normal sag is determined for each specimen preparatory to the initial loading.

At first the permanent distortions were checked against unloaded samples, but, owing to unforeseen difficulties in the method, it was abandoned for the following:

Before applying loads the sag readings were taken for both sides of each specimen and the initial set recorded as half the difference between these readings. The apparent distortion was determined in a similar way after the loads had been removed and time allowed for recovery. The difference between the apparent distortion and the initial distortion was recorded as the actual permanent distortion. Owing to the fact that the loads imposed on the specimens and the thickness of the specimens themselves were variable quantities, possibly the distortions would be better related to the extreme fiber stresses which may be computed from the empirical formula (11) above. However, this would give but an approximate figure on which to base comparisons of distortions. It is true that the stress on the extreme fiber is responsible for most of the distortion in the specimen, but there is quite a thickness of fibers near the surface which are contributing to the resultant permanent distortion.

8. MACHINING QUALITIES.

A method of procedure in the study of the effects of various machining operations on laminated, phenolic insulating materials is described here by a set of instructions given to machinists making such tests, as follows:

(*a*)—1. Speed of lathe, drill, or saw.
2. Shape of lathe or planer tool
3. Shape of drill point.
4. Kind of steel in machine tool.
5. Average depth of cut on lathe or shaper.
6. Effect on tool edge.
7. Performance of sample under test.
8. Perfectness of thread.
9. Heating of drill.
10. Nature of chips.

(*b*)—1. In your opinion, which sample machines the easiest?
2. How do you judge this?
3. Which has the better machined surface?
4. Which affects the tool least?
5. General opinions.

Record the results on each sample as machined.

TESTS.

Test No. 1.—Sawing data—ease of sawing, finish of cut edge, speed of saw, diameter, number of teeth per inch, grinding of saw, set. Opinions on sawing various grades to be given after sawing the samples for these tests.

Test No. 2.—Samples 5 inches in length to be submitted to permit turning a 3½-inch rod in the center of the sample. The samples are to be cut ½ inch square and the 3½-inch section turned down to ⅜ inch. The same tool to be used on all samples, and it shall be ground the same way for each sample. Give written report as outlined in (*a*) and (*b*).

Test No. 3.—Samples to be turned similar to No. 2. After a 3 by ⅜ inch section has been turned, then regrind the tool to a perfect point (use microscope) and make four cuts over the 3-inch length, each cut being 0.5 mm deep. Again inspect the tool with a microscope. Record results on each sample, also give written report as outlined in (*a*) and (*b*).

Test No. 4.—Samples to be cut 3 inches long and ½ by ½ inch and a portion of each sample turned to a rod of such a diameter to permit the cutting of a machine thread by a screw-cutting lathe, the threaded portion being 1 ½ inches long with a ¼-inch—20 thread. Give written report as outlined in (*a*) and (*b*).

Test No. 5.—Samples to be cut and turned as in No. 4, so that the same type and size of thread may be cut by using a die, the samples to be threaded while in chuck. Use lard oil. Give written report as outlined in (*a*) and (*b*).

Test No. 6.—Drill four holes in each 2 by 2 by ½ inch sample and find how diameter of hole varies from drill size. Measure on both sides of sample. How does grinding drill off-center affect size of hole? Give written report as outlined in (*a*) and (*b*).

Test No. 7.—Tap four holes in each 3 by 3 by ½ inch sample, using tap to match die used in No. 5. Use drill as specified for metal tapping. If undersized drill be recommended, state how much smaller you would suggest drill to be, than recommended for metal. Use lard oil. Give written report as outlined in (*a*) and (*b*).

Test No. 8.—Samples to be cut 2 by 2 by ½ inch. Drill and tap a ¼-inch—20 thread 1 inch deep in each sample parallel to grain. Do not brace the sides while drilling or tapping.

Test No. 9.—Plane grooves in each sample ½ inch wide and ¼ inch deep as per sketch (see 5 and 6, Fig. 28). Use shaped tool, with sufficient clearance. Do not back the sample in any way. Sample 2 by 2 by ½ inch. Give written report as outlined in (*a*) and (*b*).

VI. THERMAL EXPANSIVITY.

The bureau has made a rather thorough study of the expansion [3] of various insulating materials of the phenol-methylene type. The methods developed in that study are briefly outlined here.

The specimens were cut from sheets of the laminated materials, each specimen being about 1 cm square by 30 cm long. The ends of the test samples were shaped to conform to the special apparatus used. Two kinds of apparatus [4] were used in making the thermal expansion tests—an oil bath [5] and an air furnace.

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[3] Scientific Paper 352, "Thermal Expansion of Insulating Materials," by Wilmer H. Souder and Peter Hidnert.

[4] This was essentially the apparatus designed and installed by A. W. Gray and L. W. Schad, formerly of this bureau.

[5] For short description, see Preliminary Determination of the Thermal Expansion of Molybdenum, Scientific Paper 332, p. 31, by L. W. Schad and Peter Hidnert.

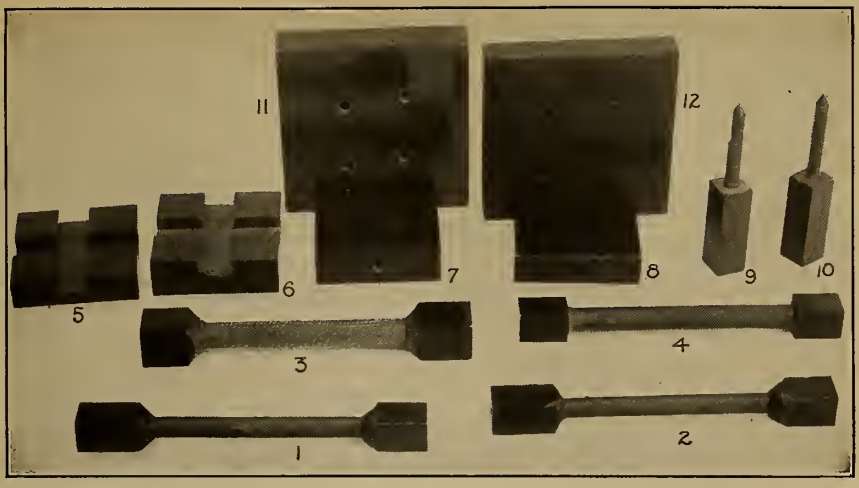

FIG. 28.—*Samples used to determine machining qualities.*

Samples 1 and 2, machined according to test No. 3; samples 3 and 4, according to test No. 2; samples 5 and 6, according to test No. 9; samples 7 and 8, according to test No. 8; sample 9, according to test No. 5; sample 10, according to test No. 4; and samples 11 and 12, according to test No. 7.

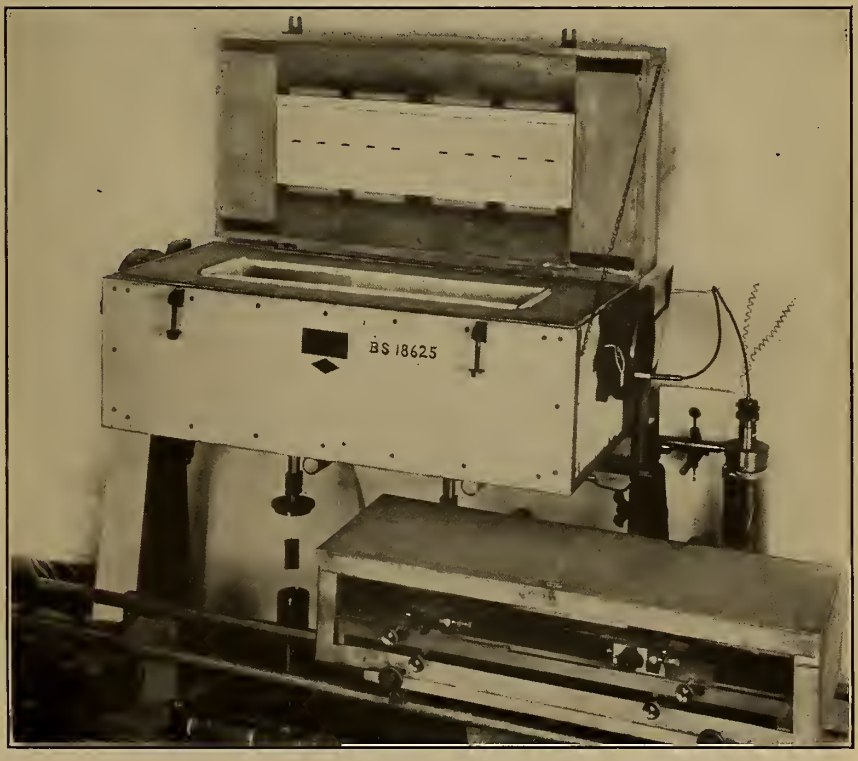

FIG. 29.—*Furnace and traveling microscopes used in measuring thermal expansivity.*

In the furnace the specimen was supported horizontally and a 2-mil platinum wire, which was previously annealed, hung over each end. Each wire, hanging through a hollow tube below the end of the specimen and extending downward through and below the furnace, had at its lower end a vane (or weight) immersed in oil in order to damp the vibrations. Heating was effected by electric resistance coils (outside, inside, and end coils). With careful manipulation it was possible to adjust the circuits so that during an observation the specimen was at a uniform temperature within one-tenth degree centigrade from end to end.

The length changes were determined with a comparator consisting of two microscopes rigidly clamped on an invar bar at a distance from each other equal to the length of the specimen (30 cm). The microscopes were so arranged that they could first be sighted on a standard-length bar kept at constant temperature, and then on the vertically suspended wires which were in contact with the ends of the specimen.

The apparatus shown by Figure 29 was used for part of this research and portrays the essential method of making observations on materials. The furnace is shown with the top lifted. The traveling microscopes, which are sighted (simultaneously) on the two vertical wires hung from the specimen, are displaced to the right in order to show the construction of the tube protecting the vertical or drop wires. The left oil pot is removed to show the weight attached to the wire. The temperatures in the oil bath and furnaces were determined by means of a copper constantan and a platinum, platinum-rhodium thermocouple, respectively.

VII. EFFECTS OF CHEMICALS.

A test of the effects of sulphuric acid and sodium hydroxide (caustic soda) is recommended for the laminated phenolic materials. The test used in previous work of this kind was limited, in that the samples were immersed in the solutions for 48 hours only, and only one strength of solution was tried. To give a more complete knowledge of the effects of these solutions, solutions of different densities should be used and the samples immersed for 30 to 60 days, determining the weight and hardness at specified intervals. The samples were cut 5 by 10 cm by the thickness of the material, which in all cases was about 1.3 cm.

The method of procedure is summarized in the following directions for testing:

1. Determine the hardness (by the Brinell method) and the weight of each sample before placing in the solution.

2. Prepare a solution of sulphuric acid (22 per cent H_2SO_4 by weight) and allow the solution to stand until it is at room temperature. Prepare a similar 17 per cent solution of sodium hydroxide. State the room temperature.

3. Immerse one of each pair of like samples in the acid solution and the other in the caustic solution. Arrange the samples in the solutions so that they will stand on end, with a sufficient layer of solution surrounding each sample.

4. At the end of 48 hours remove the samples and gently wash them to remove surface solution. Do not rub the samples in the washing or dry them with a cloth. Stack them to dry as they were stacked in the solutions.

5. After the samples have stood in the room (out of strong drafts and direct sunlight) for 24 hours weigh each sample and give the increase or decrease in weight.

6. Let the samples stand an additional 24 hours, weigh again, and state the additional increase or decrease in weight.

7. Determine the Brinell hardness after the above treatment.

VIII. CONCLUSION.

The methods described in this paper are the ones that were used in the research described in the authors' paper, Properties of Electrical Insulating Materials of the Laminated, Phenol-Methylene Type, B. S. Technologic Paper No. 216. As there stated, the research was carried on cooperatively by a number of sections of the Bureau of Standards. Credit for the methods of measurement is due the members of the sections having to do with the several properties. The methods are, in general, suitable for comprehensive study of most electrical insulating materials.

WASHINGTON, October 26, 1922.

CORRECTION SHEET FOR

BUREAU OF STANDARDS SCIENTIFIC PAPER NO. 472

Page 81, line 12. Bold face ***d*** should be light face d.

Page 81, line 26. Bold face ***u*** on line 3 of equation (4) should be light face u.

Page 85. Bold face ***n*** in first two equations should be light face n.

Page 85. In line ending "$=\lambda$" bold face ***a*** preceding "$=\lambda$" should be light face a.

Page 88. In line beginning "$\Sigma \log rs =$" the first parenthetical expression should be an exponent of the s preceding it; viz:

$$\log s^{\frac{N-1}{2}}$$

Page 89. All bold face ***n***'s should be light face n's.

Page 89. In the line beginning "the above formula," the mathematical expression should be

$$U_{\frac{n-1}{n}}$$

In the next line, the expression should be

$$\lambda V_{\frac{n-1}{n}}$$

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